Multiplicity measurements at COMPASS

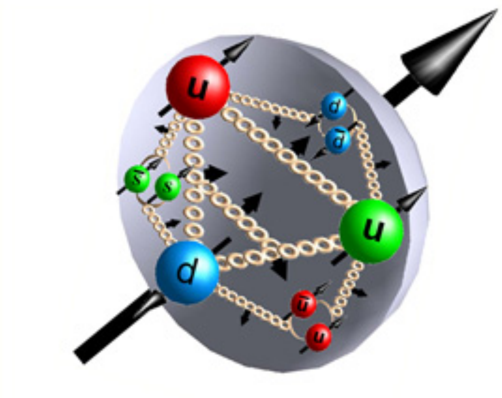
Claude MARCHAND, on behalf of COMPASS collaboration

CEA Saclay, IRFU, Service de Physique Nucléaire

1. Motivation
2. COMPASS experiment
3. Multiplicities
4. Fragmentation functions

Nucleon structure

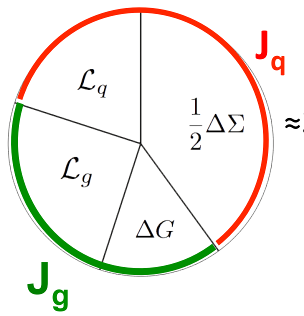
Proton structure



- 3 valence quarks
- Gluons
- Sea quarks

Spin structure

$$\frac{S_z^N}{\hbar} = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_z^q + L_z^g$$



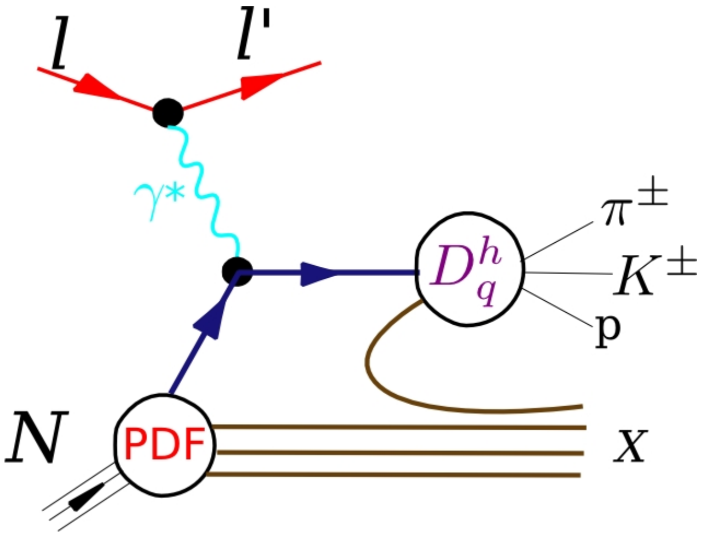
≈30% : **Spin puzzle**

$$\Delta\Sigma = \int \left[(\Delta u(x) + \Delta\bar{u}(x)) + (\Delta d(x) + \Delta\bar{d}(x)) + (\Delta s(x) + \Delta\bar{s}(x)) \right] dx$$

Deep Inelastic Scattering

$$A_1(x,Q^2) = \frac{\sigma_{\uparrow\downarrow}-\sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow}+\sigma_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

SIDIS sensitive to PDF and FF



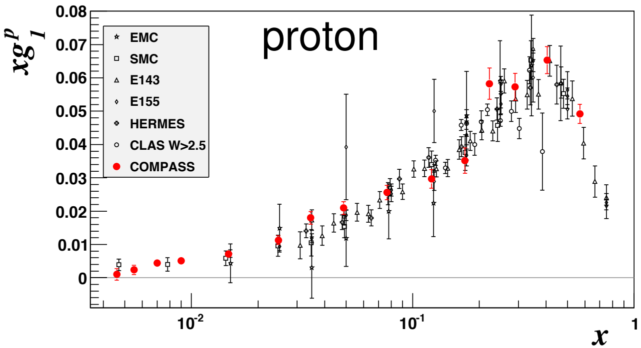
Inclusive deep inelastic scattering (DIS)	
$l\,N \rightarrow l'\,N + X$	
Kinematic variables	Q^2 : photon virtuality (γ^*) x: Bjorken scaling variable y: Inelasticity
Cross section	$\sigma \sim \mathrm{PDF}(x,Q^2)$

Semi inclusive deep inelastic scattering (SIDIS)	
$l\,N \rightarrow l'\,N\,\mathbf{h} + X$	
Kinematic variables	z: Fraction of energy
Cross section	$\sigma \sim \mathrm{PDF}(x,Q^2) \cdot D_q^h(z,Q^2)$

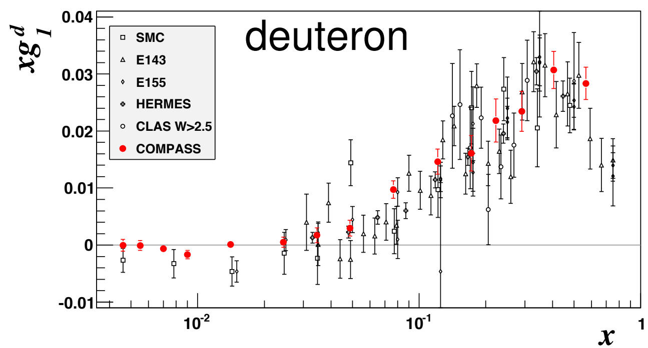
$$A_1^{h\,(p/d)}(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

New A_1^p & g_1^p from 2011 200 GeV data

Phys. Lett. B 690 (2010) 466

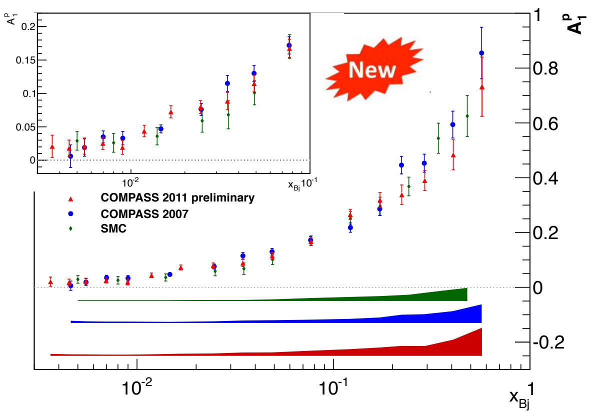


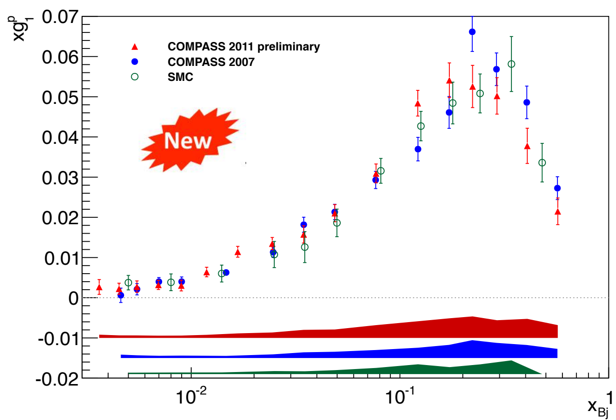
Phys. Lett. B 647 (2007) 8



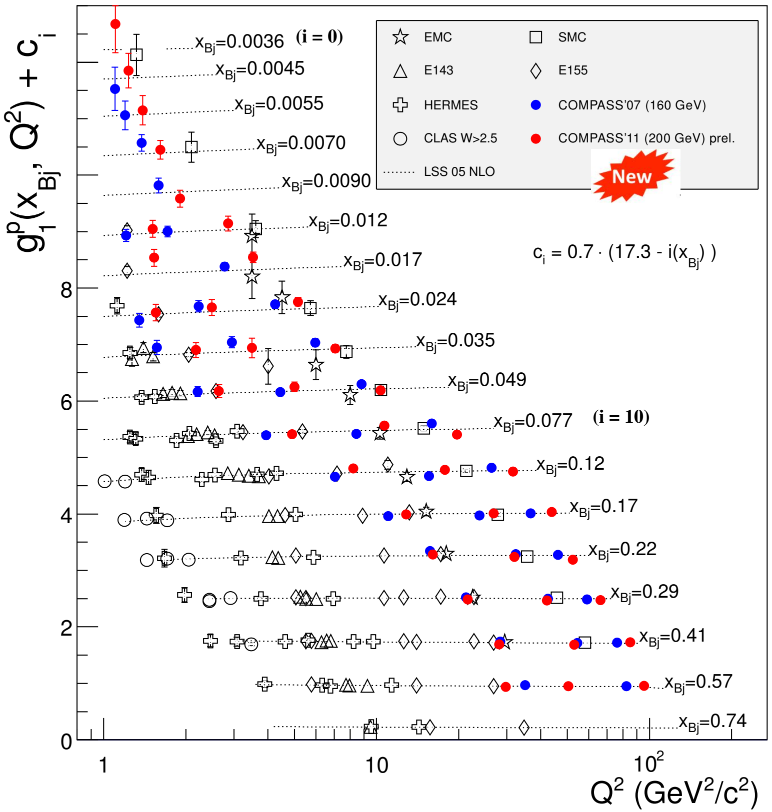
COMPASS new 2011 proton data: 200 GeV muon beam

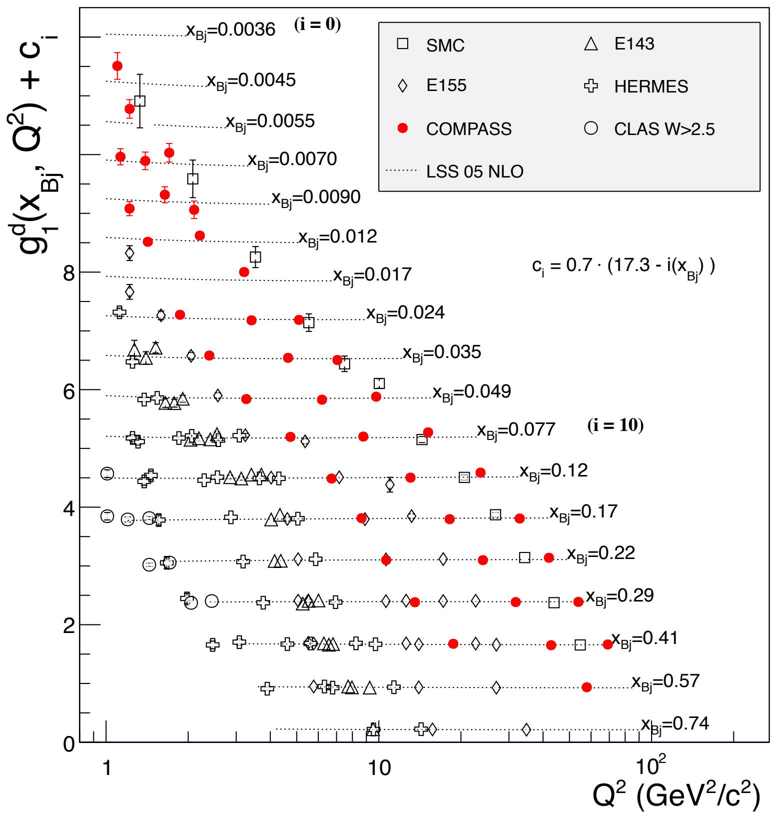
→ lower x, higher Q^2, improve statistics on proton, Bjorken sum rule





New world data on $g_1^{p,d}(x,Q^2)$



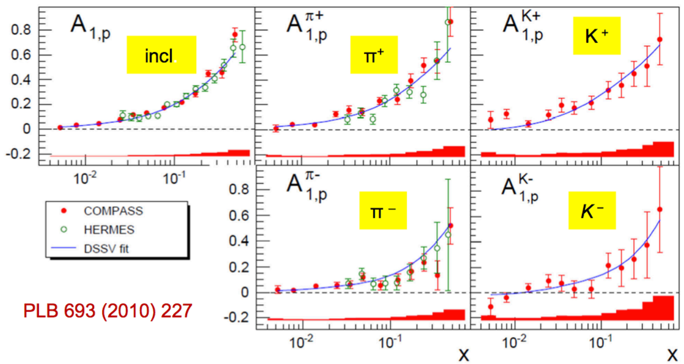


Polarized PDF from SIDIS

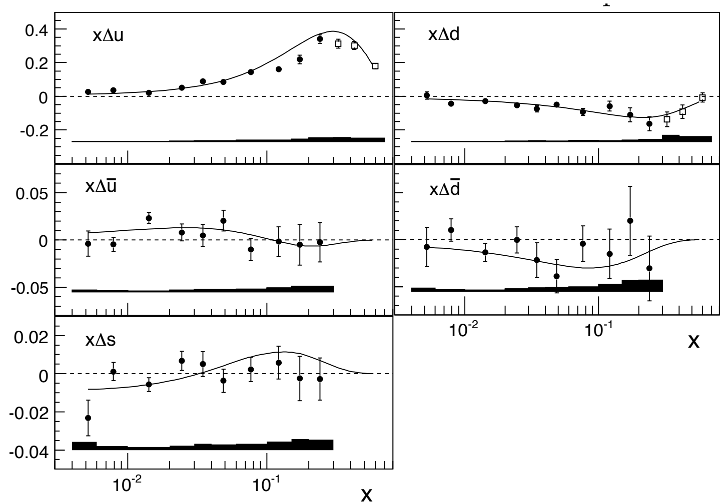
$$A_1^{h\,(p/d)}(x,z,Q^2) \approx \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

- **Inputs needed for the extraction of $\Delta q(x, Q^2)$:**
  - Unpolarised PDFs ($q(x, Q^2)$) $\rightarrow$ MRST04
  - $D_q^{\,h}(z, Q^2) \rightarrow$ DSS parameterisation

PRL 101 (2008) 072001; PR D80 (2009) 034030



PLB 693 (2010) 227



Soon: new 2011 data

Leading Order (LO) fit of the 10 asymmetries (5d+5p)

Determine 6 flavor separated PDFs $\Delta u,\ \Delta d,\ \Delta\bar{u},\ \Delta\bar{d},\ \Delta s$ and $\Delta\bar{s}$

Good agreement between COMPASS data and DSSV parametrization, but…

Strange quark polarization

Contribution from strange quark to nucleon spin: $$\Delta S = \int_{x_{min}}^{x_{max}} (\Delta s(x) + \Delta \bar{s}(x))dx$$

DIS data + semi leptonic decay of baryons:

ΔS = -0.08±0.02±0.02

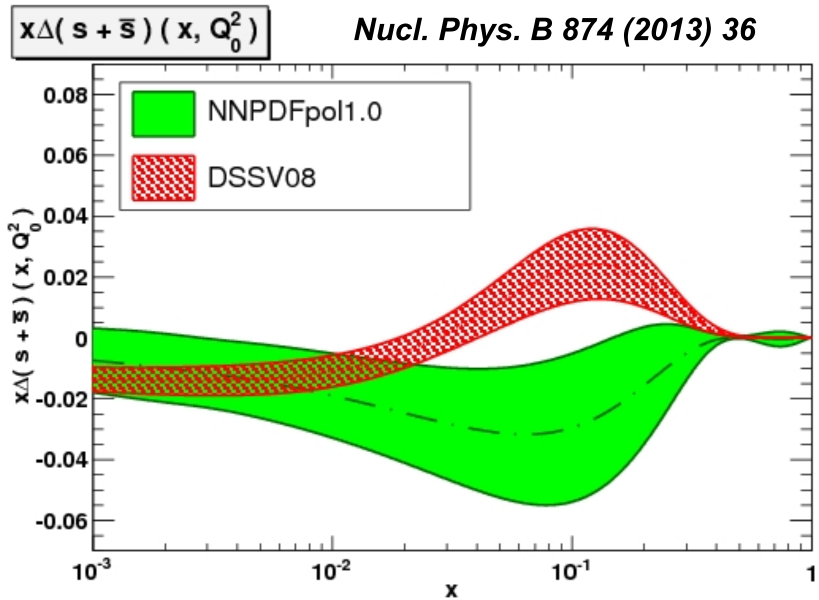
Phys. Lett. B 647 (2007) 8

DIS + SIDIS data:

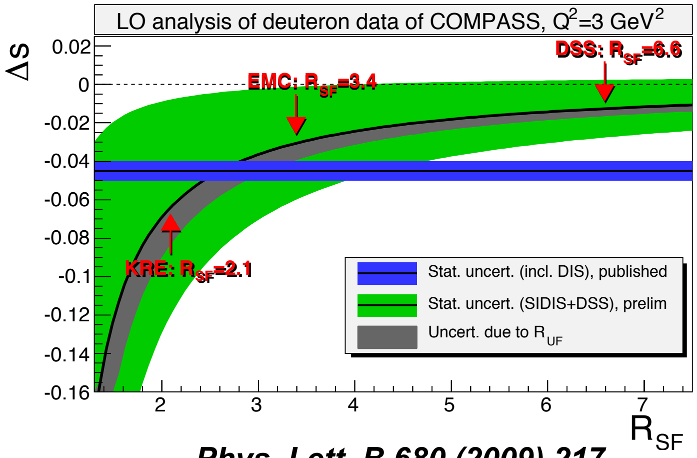
ΔS = -0.02±0.02±0.02

Phys. Lett. B 693 (2010) 227

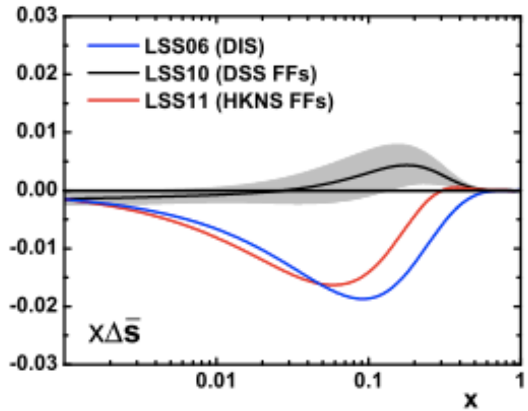
Nucl. Phys. B 874 (2013) 36



Strange quark polarization



Phys. Lett. B 680 (2009) 217



LSS: ArXiv:1103.5979

$$R_{SF} = \frac{D_s^K}{D_u^K}$$

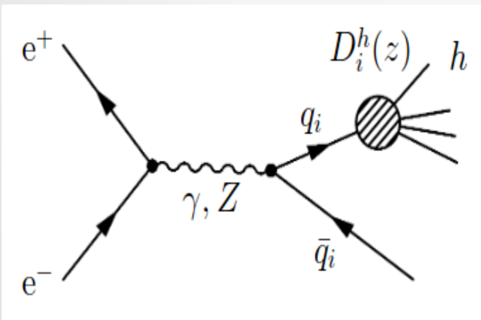
ΔS extracted from SIDIS depends strongly on choice of FF used for K: HKNS, DSS, AKK, ….. they differ strongly for D_s^K

→ need for more SIDIS data to better constrain K FF

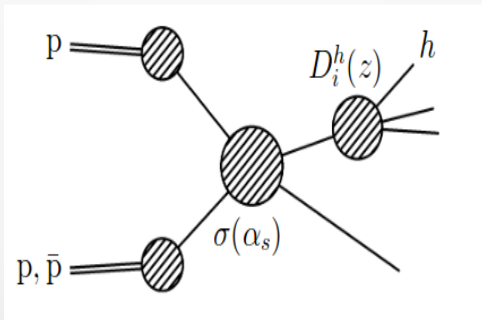
Reactions sensitive to FF

Acces to FF possible via high energy reactions:

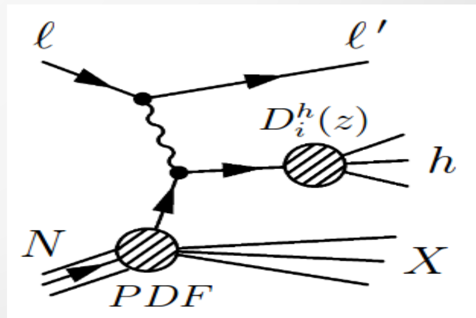
e^+e^- annihilation
(into hadrons)
(Belle & BABAR)
- High precision data
- No dependence on PDF
- Access to singlet combination only
  $(D_\Sigma = D_{\bar{u}}^h + D_d^h + D_s^h + \ldots)$



Hadron-hadron collision
(RHIC, Fermi Lab, ..)
- High precision data
- Flavor/charge separation
- Sensitive to gluon FF
- Dependence on PDF



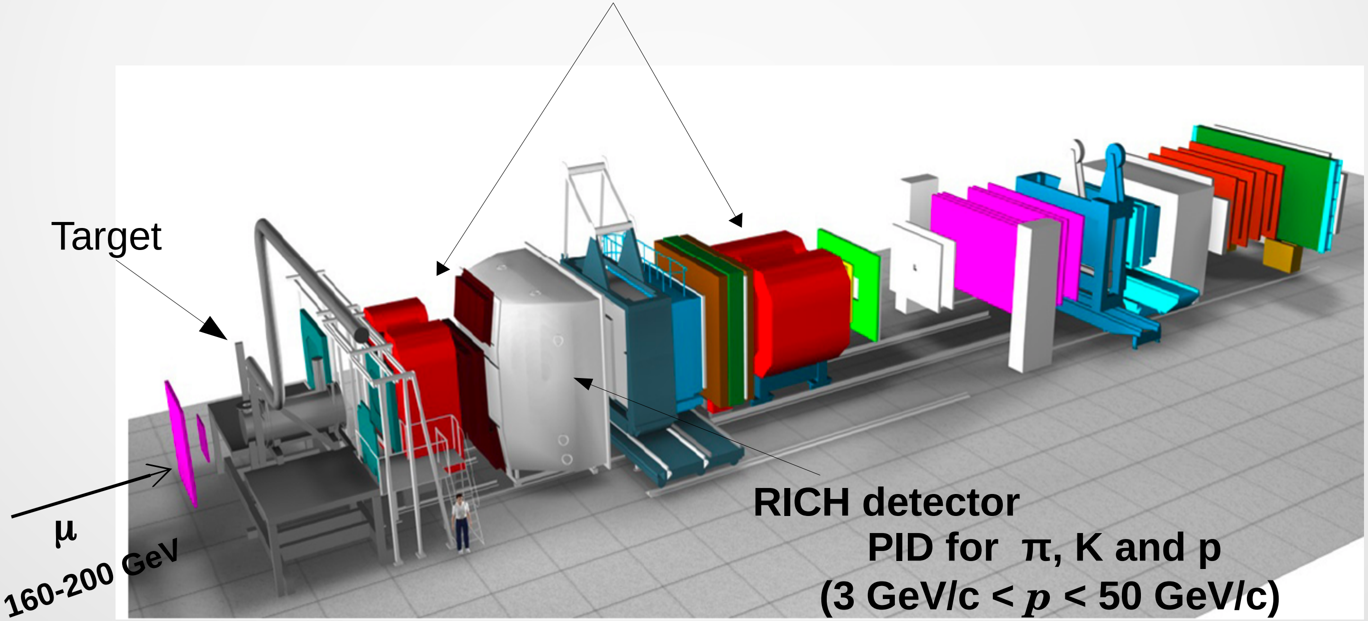
Lepton-hadron collision
(COMPASS, HERMES, JLab)
- High precision data
- Flavor/charge separation
- Access larger z
- Study of hadronization process
- Dependence on PDF



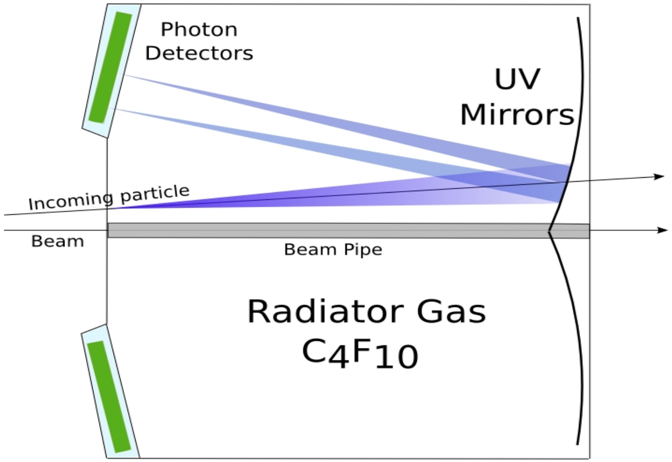
Compass setup 2002-2011

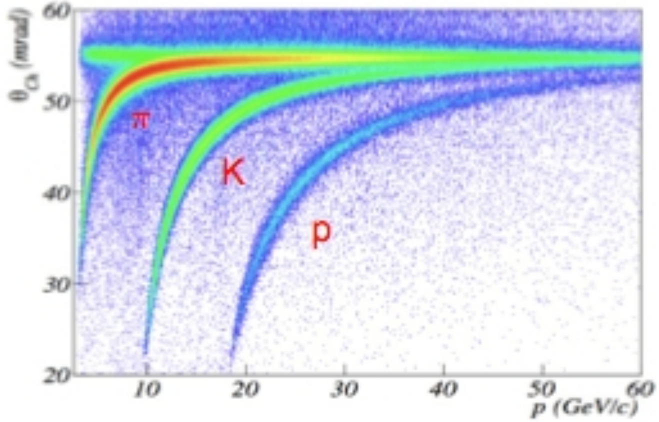
Beam: 160 (200) GeV $\vec{\mu}^+$, pol. 80%

- Fixed target at CERN
- ^{6}LiD target (2006)
- Two stage spectrometer
- Tracking and particle identification
- High acceptance



Particle ID (RICH)





- Separate π, K and p in a high-intensity environment
- Covers full spectrometer acceptance
- Mirror system ~ 22 m^2
- Photon detection system: MWPC + MAPMT

Particle identification algorithm

- Photon trajectory reconstruction → Θ_{CH} measured
- Maximum likelihood estimator
  - 5 mass hypothesis (e, μ, π, K and p)
  - Background hypothesis
- Maximum of 6 likelihood → good hypothesis

Hadron multiplicities in SIDIS

Relevant observables: **Hadron Multiplicities**

$$M^h(x,Q^2,z) \equiv \frac{dN^h/dz}{N_{\mathrm{DIS}}} = \frac{\sum_q e_q^2 \left[q(x,Q^2)D_q^h(z,Q^2) + \bar{q}(x,Q^2)D_{\bar{q}}^h(z,Q^2)\right]}{\sum_q e_q^2 \left[q(x,Q^2) + \bar{q}(x,Q^2)\right]}$$

Knowledge of unpolarised PDFs essential

- u(x), d(x) well known
- ***s(x) poorly known ⇔ can be accessed from hadron multiplicities***

Kinematic dependence on x, Q^2, z:
→ Binning in x, Q^2, z required
→ High statistics needed

Flavor separation:
→ Particle identification required

Requirements fulfilled by COMPASS

in the kinematic domain

$Q^2 > 1$ GeV^2, W > 5 GeV, $0.1 < y < 0.7$, $0.004 < x < 0.7$, $0.2 < z < 0.85$

Multiplicity measurement

$$M = \frac{N^h}{N_{DIS}\,\Delta z}$$

Acceptance correction

- Simulate DIS events with physics generator (LEPTO) => M_{gen}
- Simulate the detector response using GEANT toolkits and reconstruct data => M_{rec}
- Estimate acceptance correction factor for limited geom. and reconstruction efficiency $a = M_{rec}/M_{gen}$
- Correct real data:

$$M_{cor} = \frac{M_{raw}}{a}$$

Particle identification

- Measure identif./misidentif. Probability matrix

$$\begin{pmatrix} I_\pi \\ I_K \\ I_p \end{pmatrix} = \underbrace{\begin{pmatrix} P^{\pi\to\pi} & P^{K\to\pi} & P^{p\to\pi} \\ P^{\pi\to K} & P^{K\to K} & P^{p\to K} \\ P^{\pi\to p} & P^{K\to p} & P^{p\to p} \end{pmatrix}}_{=P} \begin{pmatrix} T_\pi \\ T_K \\ T_p \end{pmatrix}$$

And unfold data :

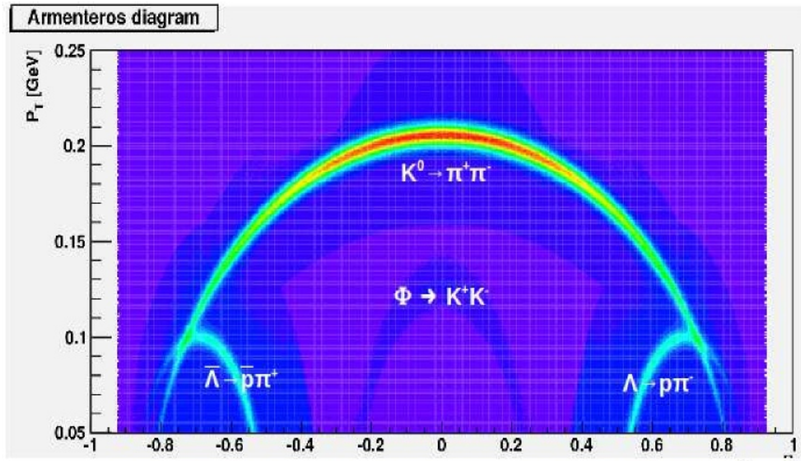
$$\boxed{\vec{T} = P^{-1}\vec{I}}$$

RICH efficiency matrix

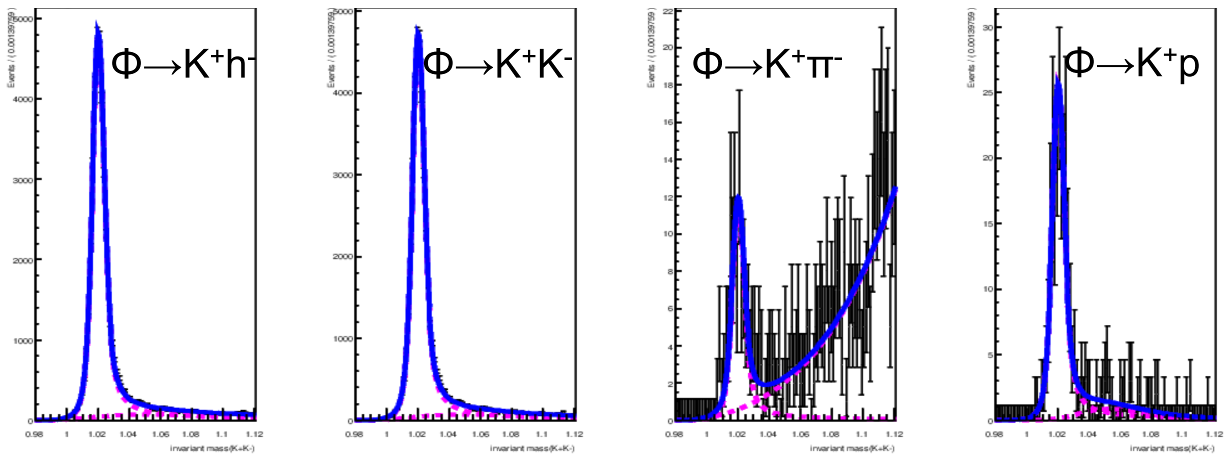
Use pure sample of π, K, p from decays:

- $K^0 \rightarrow \pi^+\pi^-$
- $\Phi \rightarrow K^+K^-$
- $\Lambda \rightarrow \pi^- p$

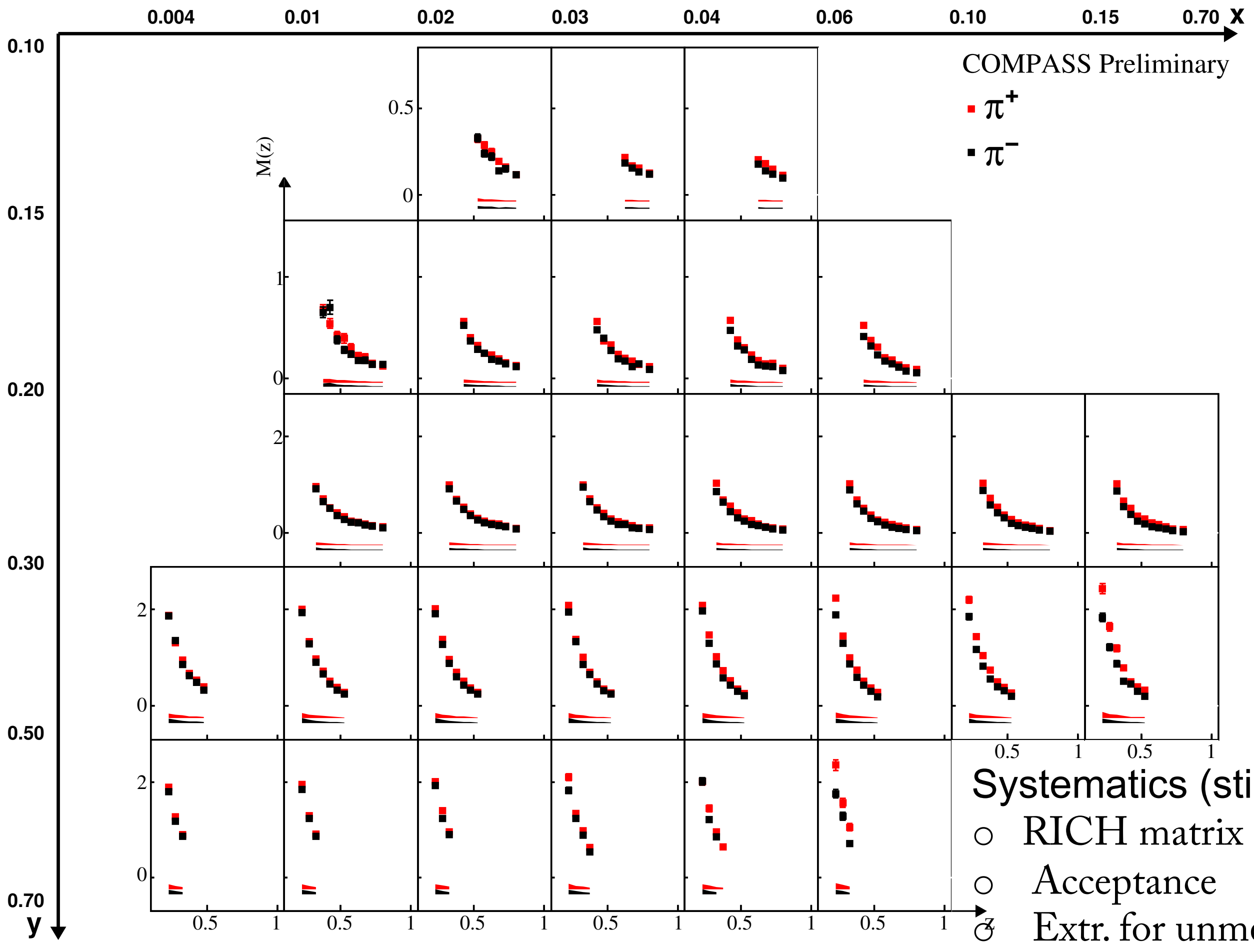
- Momentum range: 10-40 Gev/c (10 bins)
- Angular range: 0.01-0.12 rad (2 bins)



$$\alpha = \frac{P_{1L} - P_{2L}}{P_{1L} + P_{2L}}$$



Pion multiplicities



Systematics (still in progress):

- RICH matrix
- Acceptance
- Extr. for unmeasured mom. range

Possible extraction of FF

Use symmetries to reduce number of independent FF

$$D^{\pi}_{fav} = D^{\pi^\pm}_{fav} = D^{\pi^+}_{u} = D^{\pi^+}_{\bar{d}} = D^{\pi^-}_{\bar{u}} = D^{\pi^-}_{d}$$

isospin

C.C.

$$D^{K}_{fav} = D^{K^\pm}_{fav} = D^{K^+}_{u} = D^{K^-}_{\bar{u}}$$

$$D^{K}_{str} = D^{K^\pm}_{str} = D^{K^+}_{\bar{s}} = D^{K^-}_{s}$$

Pions:

$$D^{\pi}_{unf} = D^{\pi^\pm}_{unf} = D^{\pi^+}_{d} = D^{\pi^+}_{\bar{u}} = D^{\pi^-}_{\bar{d}} = D^{\pi^-}_{u} = D^{\pi^+}_{s} = D^{\pi^+}_{\bar{s}} = D^{\pi^-}_{s} = D^{\pi^-}_{\bar{s}}$$

Kaons:

$$D^{K}_{unf} = D^{K^\pm}_{unf} = D^{K^+}_{s} = D^{K^+}_{\bar{u}} = D^{K^-}_{\bar{s}} = D^{K^-}_{u} = D^{K^+}_{d} = D^{K^+}_{\bar{d}} = D^{K^-}_{d} = D^{K^-}_{\bar{d}}$$

$$D^{\pi}_{glu} = D^{\pi^\pm}_{glu} = D^{\pi^+}_{g} = D^{\pi^-}_{g}$$

$$D^{K}_{glu} = D^{K^\pm}_{glu} = D^{K^+}_{g} = D^{K^-}_{g}$$

Possible extraction of FF

➜In case of deuterium target, π multiplicities reduce to following formula:

$$M^{\pi^+}(z_0 \pm dz, Q^2) = \frac{(4(u+d)+\bar{u}+\bar{d})\mathbf{D}^{\pi}_{\mathbf{fav}} + (u+d+4(\bar{u}+\bar{d})+2(s+\bar{s}))\mathbf{D}^{\pi}_{\mathbf{unf}}}{5Q+2S}$$

$$M^{\pi^-}(z_0 \pm dz, Q^2) = \frac{(u+d+4(\bar{u}+\bar{d}))\mathbf{D}^{\pi}_{\mathbf{fav}} + (4(u+d)+\bar{u}+\bar{d}+2(s+\bar{s}))\mathbf{D}^{\pi}_{\mathbf{unf}}}{5Q+2S}$$

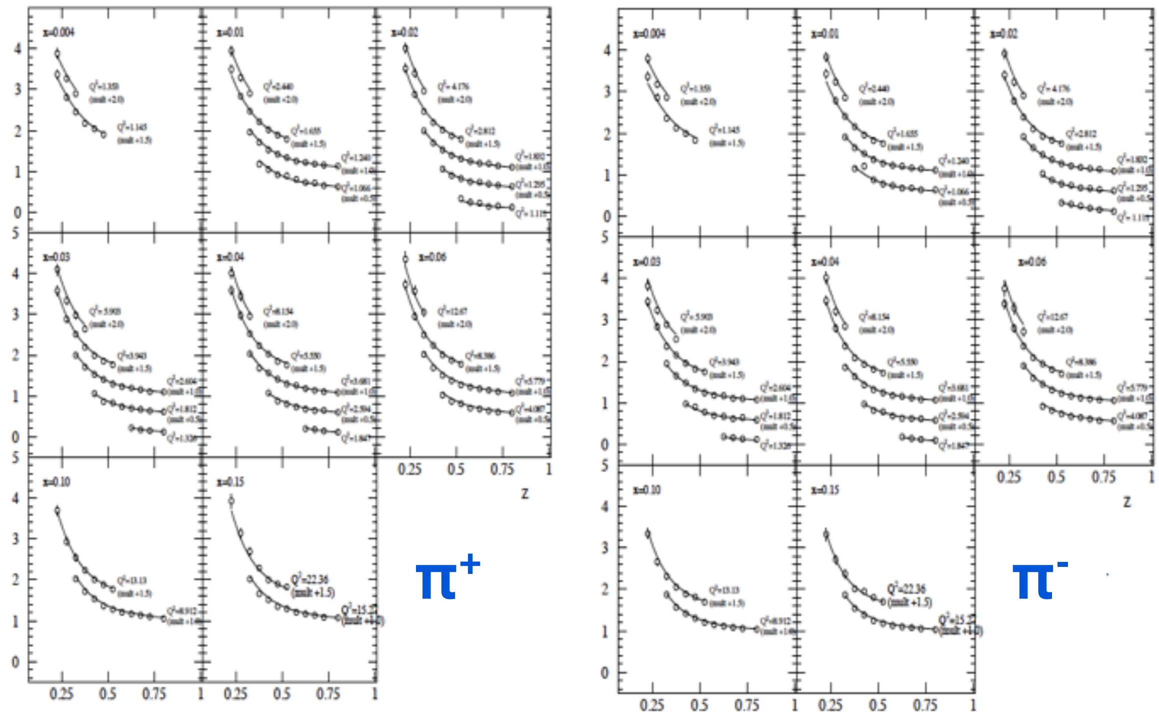
$$Q = (u+\bar{u}+d+\bar{d}) \; ; \; S = (s+\bar{s})$$

- For each (x,y,z) bin, 2 equations with two unknowns → D_{fav}(x,y,z), D_{unf}(x,y,z)
- Or do a global fit with known parametrizations for D_q^h (usually: $z^\alpha.(1-z)^\beta$):
  - fix parametrization at input scale (e.g. Q_0^2=1 (GeV/c)^2)
  - evolve FF using DGLAP equations (e.g. Hirai-Kumano, 1106.1553)

DSS preliminary NLO fit

DSS$^{\beta}$ snapshot: COMPASS μp multiplicities

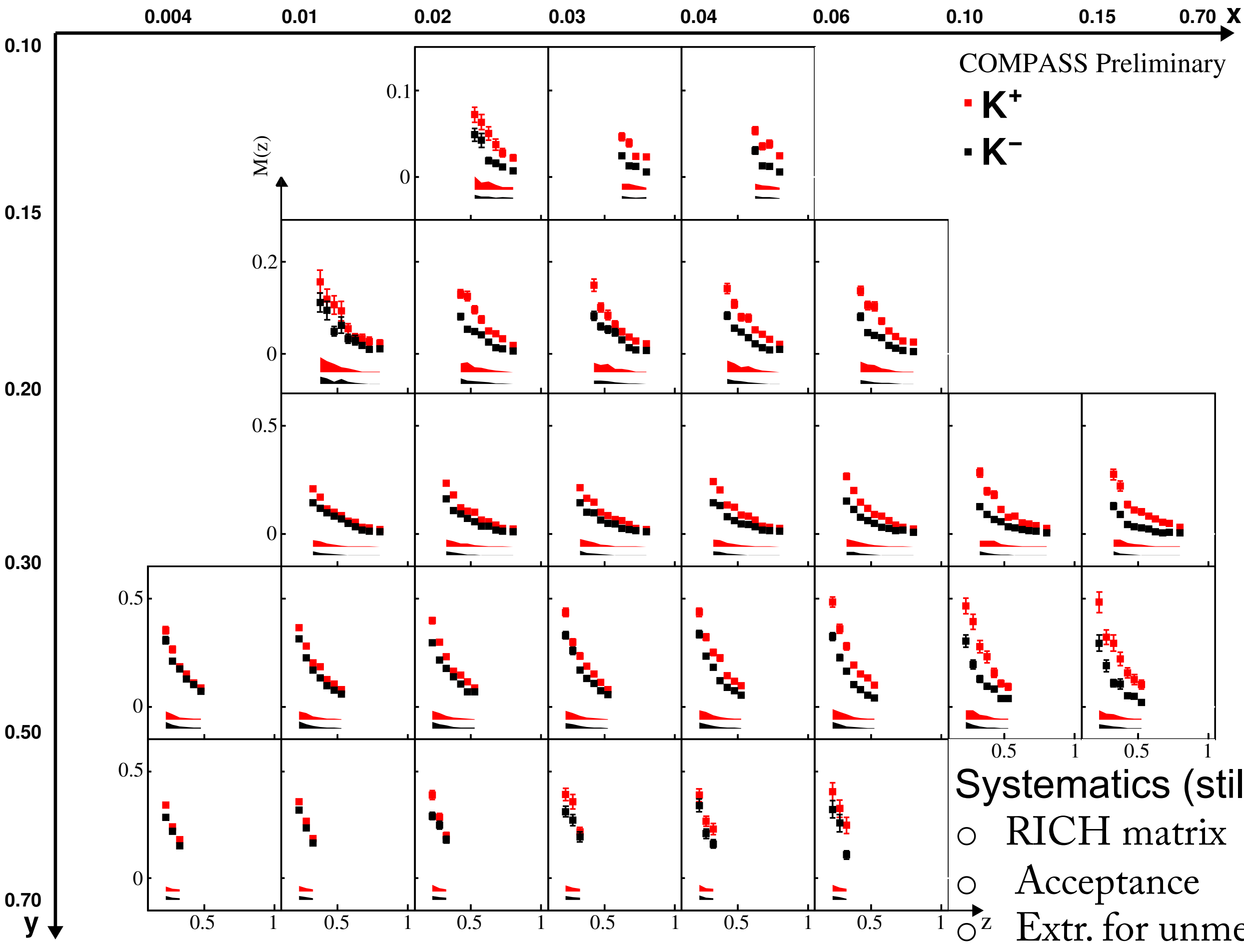
FOR YOUR EYES ONLY



20

Courtesy: M. Stratmann, Berkeley 2013

Kaon multiplicities



Systematics (still in progress):

- RICH matrix
- Acceptance
- Extr. for unmeasured mom. range

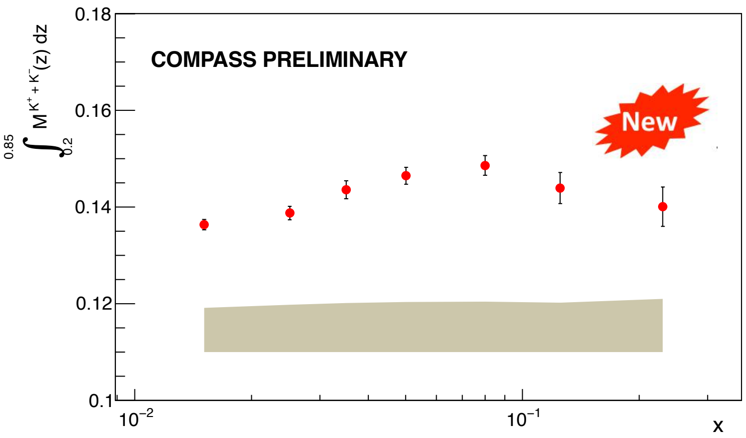
Sensitivity of M^K to strange FF D_s^K

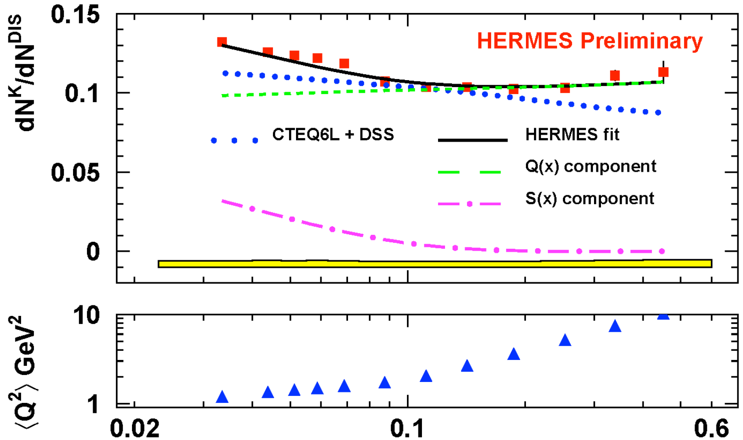
$$\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{Q(x)\int D_Q^K(z)dz + S(x)\int D_S^K(z)dz}{5Q(x)+2S(x)}$$

$\xrightarrow{2S(x) \ll 5Q(x)}$

$$\int_{0.2}^{0.85} M^{K^+ + K^-}(x,z)dz = \frac{1}{5}\left(\int D_Q^K(z)dz + \frac{S(x)}{Q(x)}\int D_S^K(z)dz\right)$$

Directly related to strange PDF and FF of strange quark into K





Arxiv 1212. 5407 & H. Jackson DIS'13

Small x dependence → small $D_s^K(z)$ or $S(x)$

solves tension for Δs between DIS & SIDIS ?

Tension with HERMES?
more work needed

Hadron multiplicities vs p_T^2

Differential SIDIS cross-section

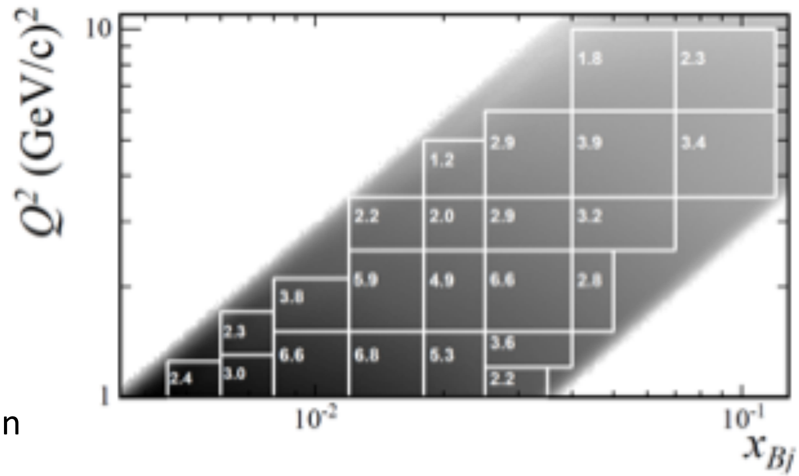
$$\left.\frac{d^2 n^{h\pm}(z, p_T^2, x_{Bj}, Q^2)}{dz\, dp_T^2}\right|_{\Delta x_{Bj} \Delta Q^2} \approx \frac{\Delta^4 N^{h\pm}(z, p_T^2, x_{Bj}, Q^2)/(\Delta z \Delta p_T^2 \Delta x_{Bj} \Delta Q^2)}{\Delta^2 N^{\mu}(x_{Bj}, Q^2)/(\Delta x_{Bj} \Delta Q^2)}$$

SIDIS data collected in 2004 with ^{6}LiD target

Kinematic range

- $Q^2 > 1$ GeV^2
- $0.1 < y < 0.9$
- W > 5 GeV

23 x, Q^2 intervals



Multi-dimensional analysis:

23 x, Q^2 intervals

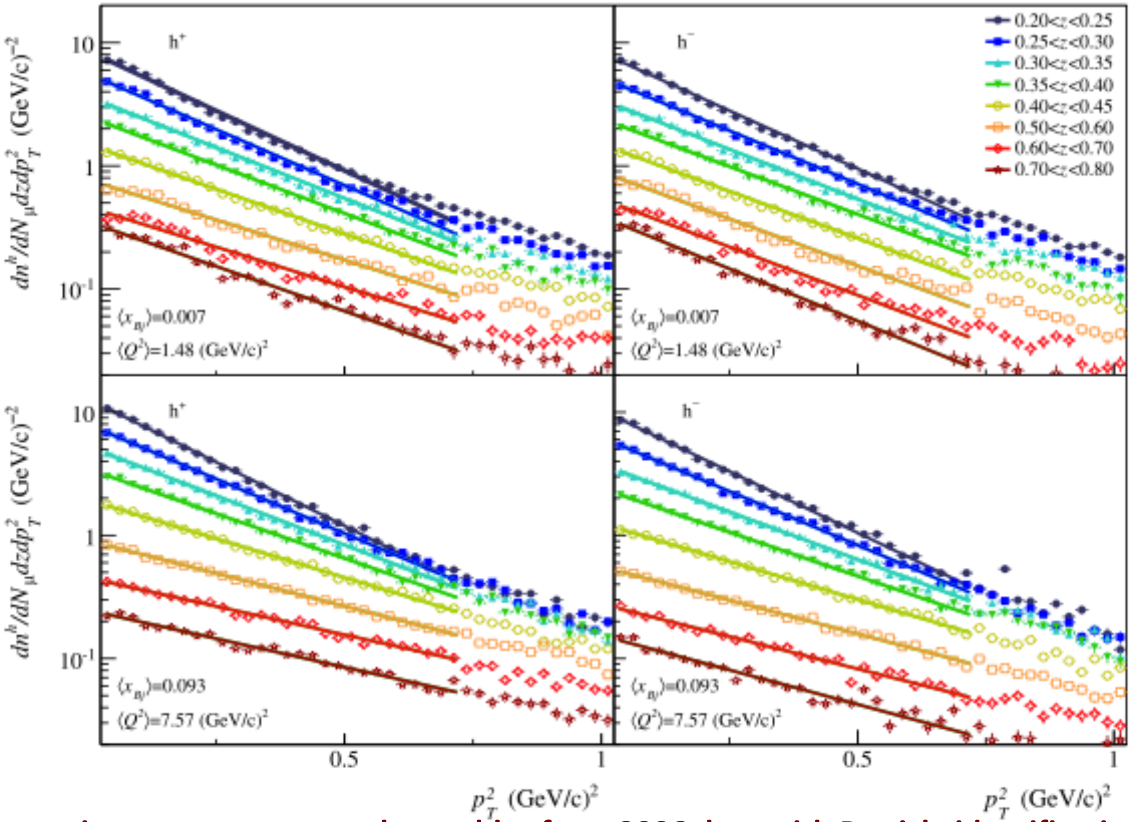
8 z bins and 40 p_T^2 bins

4-dimensional acceptance correction

5% systematic uncertainties

Hadron multiplicities vs p_T^2

EPJC 73(2013) 2531



Work ongoing to extract same observables from 2006 data with Particle identification

Hadron pair multiplicities

Main motivation:

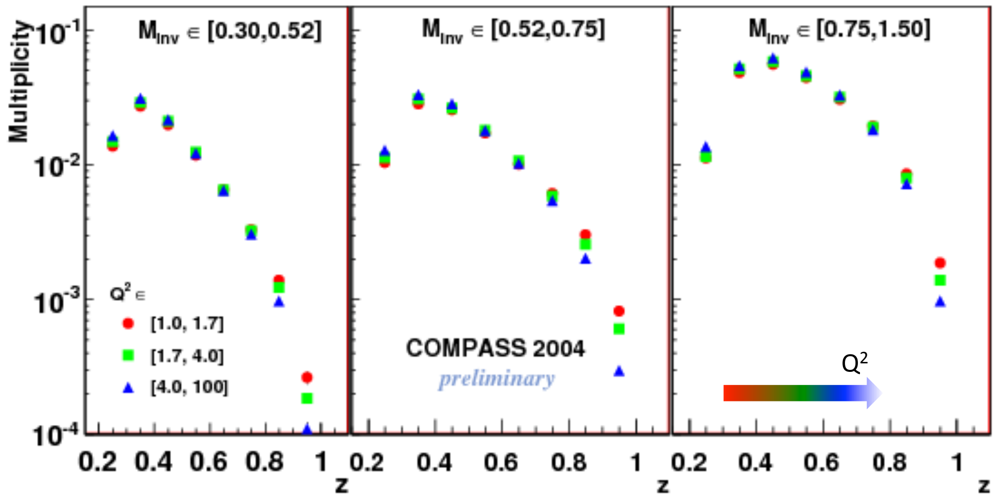
transversity from hadron pair transverse spin asymmetry (measured at COMPASS)

Interference fragmentation functions

$$A_{UT}^{\sin\phi_{RS}} = \frac{|\mathbf{p_1}-\mathbf{p_2}|}{2M_{inv}} \frac{\sum_q e_q^2\, h_1^q(x)\, H_1^{\sphericalangle,q}(z,M_{inv}^2,\cos\theta)}{\sum_q e_q^2\, f_1^q(x)\, D_1^q(z,M_{inv}^2,\cos\theta)}$$

Experimentally measured asymmetries

Unpolarised di-hadron fragmentation functions



Significant M_{inv} and $z=z_1+z_2$ dependences (as expected)

Weak Q^2 dependence

Summary

- Preliminary results on hadron multiplicities
  - Broad kinematical ranges
  - 3-Multidimensional binning
  - Identified pions and kaons

- Improved kaon identification with reduced systematic errors
  with ongoing studies to reduce systematics

- Stable FF fits for pions (eg DSS)

- First measurement of unidentified hadron pair multiplicities for the perspective of extracting Dihadron fragmentation functions

- More high precision measurement on the list
  - P_T^2 dependent pion and kaon multiplicities in (x,Q^2,z) bins
  - Identified hadron pair multiplicities in (z,Q^2,M_{inv}) bins